Optimal Trajectory Generation for Two Industrial Robots in a Shared Workspace

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1 Introduction

Optimal trajectory generation for robots in a shared workspace is of significant importance for minimizing production time and costs. Classically, industrial robots, working on the same product, are brought into the workspace sequentially in order to avoid collisions. This approach causes significant time losses. It is more efficient if both robots could work in parallel in the same workspace. This, in combination with time-optimal trajectories, results in a strong reduction of the overall production time and costs.

In this work, an algorithm is developed that computes time-optimal point-to-point trajectories for two industrial robots with collision avoidance. The input for the algorithm is the start and end position and orientation for both end effectors. While taking into account kinematic, dynamic and collision constraints, the algorithm generates the joint coordinates as a function of time for both robots.

2 Optimization problem

The algorithm is formulated as an optimization problem and calculates $\mathbf{q}^A(t)$ and $\mathbf{q}^B(t)$, the joint coordinates for both robots as a function of time t. It minimizes the execution time T of the trajectories (this time is the same for both robots) in order to be time-optimal. Alternatively also the dissipated thermal energy in the joint motors could be minimized, or a trade off between execution time and energy dissipation can be considered. The problem is subjected to three kind of constraints:

- *Kinematic constraints*: These include limitations on the joint angles $\mathbf{q}$ and joint velocities $\dot{\mathbf{q}}$. Also the imposed start and end position ${}_w\mathbf{x}_{ee}$ and orientation ${}^{ee}_{w}\mathbf{R}$ of the end effector with respect to the world form kinematic constraints. It is also desired that the joint velocities are zero at the start and end of the motion.
- *Dynamic constraints*: These are limitations on the joint torques τ. In this work, several dynamic models (that relates τ and $\mathbf{q}$, $\dot{\mathbf{q}}$, $\ddot{\mathbf{q}}$) were implemented and compared to each other on performance.
- *Collision constraints*: As in [1] both robots are modelled as a union of convex polyhedra. Lagrangian duality is used to formulate collision constraints between the different polyhedra couples.

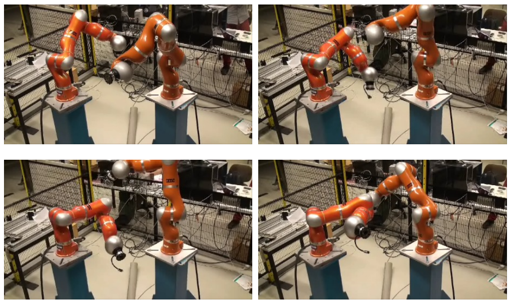

Figure 1: Trajectory generated for two KUKA LWR robots.

This problem is discretized by using B-splines for the representation of $\mathbf{q}^A(t)$ and $\mathbf{q}^B(t)$. Constraints that have to hold for the whole time domain are discretized on P time instants.

3 Iterative method

The presented optimization problem is very complex and strongly non-convex. Finding a correct solution in an acceptable time is hard. Therefore a method was elaborated in order to solve the problem iteratively with gradually increasing complexity. In this way the solution can be guided towards a satisfying local optimum.

4 Validation of the algorithm

The presented algorithm is validated and demonstrated by generating trajectories for two 7 DOF KUKA LWR robots. An example is presented in Figure 1. This problem solves in 2 min 43 s (on a 2 GHz processor with Ubuntu 12.04).

References

[1] F. Debrouwere, W. Van Loock, G. Pipeleers, M. Diehl, J. De Schutter, and J. Swevers, "Time-optimal path following for robots with object collision avoidance using lagrangian duality," in *Robot Motion and Control (RoMoCo), 2013 9th Workshop on*, pp. 186–191, 2013.

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